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THE CONQUEST OF OUTER SPACE

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16. Abstract
On the basis of the results of the OFO-A vestibular experiment on the activity of the inner ear and its control of equilibrium and the muscular and visceral systems under conditions of weightlessness the author concludes that introduction of artificial gravity aboard spacecraft is not indispensable. Should this state of affairs be confirmed for other systems of the organism, the final conclusion would be that man can adapt himself to weightlessness and therefore to living in space and on planets with a low gravitational attraction. Furthermore, closed-cycle oxygen and water bioregeneration systems could then be designed for zero G environments. Finally, with the techniques invented for the requirements of the space experiment we are now in a position to study the activity of individual elements of any biological system in normal (untraumatized) animals.

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THE CONQUEST OF OUTER SPACE

Torquato Gualtierotti

After the enthusiasm aroused by the exploit of Gagarin, the first man in space, and with the closing of the heroic era ushered in by man's "breaking away" from the earth, the space program, taken in a worldwide sense and not with reference to any particular nation, entered upon a phase of reappraisal: we are now witnessing both a more disciplined consideration of the problems and the use of the conquest of space and a violently negative reaction on the part of the man in the street, not to mention certain academic scientific circles.

As far as the first point is concerned, namely, growing awareness of the possible advantages, risks and limitations of the new medium, we can give a few examples.

At the 8th International Space Science and Technology Symposium held in Tokyo in August 1969 the Russian physicist Ivanov in his report was describing a method for indefinitely maintaining oxygen and water in physiological quantities aboard spacecraft by using cultures of a microalga (Clorella) when suddenly he broke the thread of his argument in a burst of irritation, exclaiming: "I wish we'd make up our minds once and for all whether it's indispensable to equip our spacecraft with artificial gravity; what's the point of contemplating systems of oxygen and water bioregeneration for a completely self-sufficient environment when we don't even know whether that environmnent is or is not going to be one of weightlessness?"

In early 1967, after the Gemini and Mercury flight series surprisingly had run their course with an uninterrupted absence of accidents, perhaps unique in the history of human progress, and the Soviet space program too had been attended by a similar fate, three American astronauts died in a pure oxygen holocaust in the first Apollo capsule as it was undergoing tests on the launch pad. Almost at the same time the Russian astronaut Komarov crashed to the ground in the first Soyuz on account of a defective parachute.

After the 6th Mercury mission official quarters announced that astronaut Glenn had fallen in the bathtub and suffered an alteration of the inner ear; it is not known whether this alteration is permanent, but it is certainly prolonged. More recently, at the 14th meeting of COSPAR in Seattle in June 1971, it was reported that three Russian astronauts at the end of a 26-day mission in the orbiting laboratory Salyut were found dead after an apparently perfect return to earth; nor have the causes of this misfortune yet been stated precisely.

In the meanwhile everybody's deep-seated conviction that somehow or other the American astronauts might have been able not only to survive the accident but even accomplish their space tasks -- at least up to the proven limit of 17 days -- has begun to be shaken. After having insisted for years that no insurmountable problem existed in connection with space flight, even Charles Berry (1), formerly the astronauts' physician and presently the director of the NASA Office of Life Sciences, i.e. the body in charge of all USA space biology programs, now says in one of his publications on the data of the Apollo 7-11 missions: "... the possibility of moving more freely in Apollo mission cabins, as well as in other, smaller space capsules, may be a contributing factor in motion sickness. When they reach the central nervous system during head movements in space, the afferent impulses from the semicircular canals seem to increase because of modifications of the activity of the otolithic organ consequent upon the condition of weightlessness. This is an important problem that must always be borne in mind and studied during the space program because it can appreciably alter the astronaut's performance."

Of the organic functions that have been studied up to now under these conditions Dr Berry has mentioned one that undergoes definite alterations. In the matter of the sense organs and nervous system Gagarin and Titov in Vostok 1 and 2, Glenn during the Mercury 6 mission, Schirra (Mercury 8), Cooper (Mercury 9), Nikolayev (Vostok 3), especially Yegerov, who is a physician and not a professional astronaut (Voskhod 1), and to a greater or lesser extent all the others, experienced during their flights a sensation of profound instability, the impression of spinning round and traveling head downwards. Bykovsky (Vostok 5) reported a reduced ability to move his eyeballs, and so did Tereskova, the only woman astronaut, during the same launch of 1963. Leonov, the first man to walk in space from Voskhod 2, did not experience any particular disturbance while he was outside the vehicle but felt partially disoriented in the air lock inasmuch as in that environment he had no visual reference to which he was accustomed.

As far as the vestibular problems discussed by Dr Berry are concerned, of particular importance are the symptoms of space sickness, which are rather similar to those of common motion sickness. Already before space flights a series of brief periods under practically weightless conditions (achieved by parabolic acrobatic flights) caused more or less pronounced symptoms of motion sickness in 23 out of the 45 crewmen of the airplane utilized. When improved aircraft were utilized , the number was 11 out of 24 subjects. The by now classic example for orbital flights is that of Titov, the second Russian in space, who experienced vertigoes, nausea and the sensation that the walls were revolving about him and that the spacecraft was pitching. Yegerov had fits of headachy nausea, as did Borman (Gemini 7 and Apollo 8). Schweickart and his companions (Apollo 9) suffered from nausea and headache their first few days in orbit. During the Apollo 11 mission Aldrin, after suspending treatment with antikinetic drugs, experienced motion sickness especially when he moved his head forward, but the symptoms disappeared when he resumed medication.

The cardiovascular system, the composition of the blood and the metabolism are also altered during or right after orbital flight. Fluctuations of the pulse and increase in the duration of the cardiac cycle were observed in the case of the Mercury and Gemini programs, as well as during the Vostok 6 and Voskhod 1 flights, but the most impressive symptom was that of orthostatic intolerance. This consists in a considerable drop in arterial pressure when the subject changes from a horizontal to a vertical position, and in extreme cases it may even lead to a loss of consciousness. Astronauts experience orthostatic intolerance after returning to earth, and the phenomenon is all the more pronounced, the longer the duration of the flight: after the 14-day Gemini 7 mission it lasted a good 48 hours from the moment of return. In astronaut Borman a decrease in blood volume with a loss of 20% of the red corpuscles was noticed, while the presence of immature forms in the bloodstream attested to a severe ailment of the bone marrow, which is precisely what produces new blood cells. From the metabolic point of view, after every flight evidence was found of losses of many of the minerals normally contained in the organsim, such as calcium, sodium, potassium and chlorine, as well as a considerable loss of water. Other alterations, of less seriousness, were detected in the respiration, which became either diminished, as in the case of the Mercury mission flights and Vostok 3 and 4, or considerably increased, as in the case of the space walks (Vostok 2 and Gemini 11).

Next we will take up the second point of our discourse, namely, the diffuse antagonism to space, space flights and space research. Should it be decided to continue human expansion into outer space (for example, by setting up permanent orbiting laboratories with shifts of up to 56 consecutive days for the personnel), the problem of changing from terrestrial gravity to weightlesssness and vice versa without harmful consequences will obviously become ever more presssing. In the meantime public opinion, as well as certain segments of legitimate and official -- in a word, academic -- science, is expressing some opposition to investment of funds in space research, which is the only research that can solve the problem. To give but one example, in the spring of this years Sanders of the Biology Office, Life Sciences, NASA, presented the NASA biological research program in Paris to an ESRO meeting attended by delegates from various European countries, including members of our [Italian] National Research Council. The reaction was quite negative and cloaked in sanctimonious indignation at the squandering of money that implementation of the American Agency's research plan would entail.

Apparently we are at a fundamental turning-point in the philosophy of science. The problem that confronts us is as follows: In view of the high cost of space research and space programs in general, is it justifiable to continue in this activity and, if so, through what mechanisms and what bodies shall the said research be carried on? Discussion of this matter can be broached on the example of the outcome of, as well as comments on and reactions to, what NASA authorities have called the first space biology experiment to be crowned with complete success by virtue of having not only attained by even surpassed the stated objectives: the launch of the OFO-A vestibular experiment that took place on the 9th of November of last year from the NASA base on Wallops Island, Virginia, by means of a Scout B carrier rocket. (In this connection see the article published in this same periodical, No. 6, Nov.-Dec. 1967, pp. 57-60.) In itself this experiment constitutes a good example of the pros and cons involved in the discussion of space biology programs and their relevance to scientific progress in general and man's conquest of space in particular. In point of fact OFO-A had a very precise objective; it was prepared and executed with extreme care by specialists using specially designed equipment; and it raised a storm of reactions ranging from total approval to ferocious, undocumented criticism. Prof Ades of the Bioacoustic Research Laboratory of the University of Illinois at Urbana defines this experiment as being such as "to assign to Italy a unique place in space science." On the other hand, the Biology and Medicine Committee of our National Research Council considers the project to be "lacking in true scientific interest" and wonders whether it is right for the country to tie up funds in adventures of this type.

I have quoted two extreme and contrasting voices in order to bring out the violent controversy that pervades the entire field of space activity, and especially that of biological experimentation and human participation.

A reminder of the objectives that the OFO-A experiment set itself will make it possible to evaluate its results in the field of science as well as in that of application to human space flight, and hence to suggest to the reader on the basis of a real example the terms of the general controversy to which we have referred. Within the framework of research on the activity of the inner ear and its control of equilibrium and the muscular and visceral systems, this experiment was designed to study by a method of direct recording in situ on the animal such anomalies in behavior as the otolithic system might undergo on the level of the individual sense organs (in this connection let the reader recall the above quoted remarks by Dr Berry).

A special satellite was constructed which was capable of keeping alive the experimental animals (in the present case, bullfrogs) as well as assuring a "true" state of weightlessness, i.e. one in which the gravitational attraction component was so reduced that it could not be detected by those elements of the organism that are most sensitive to it. Details concerning the biological preparations, instrumentation and data recording and transmitting methods are contained in the above mentioned article in the Nov.-Dec. 1967 issue of this periodical. Analysis and laboratory verification of the results of the seven and a half days of flight are now in progress, but it is already possible to draw a few fundamental conclusions.

The vestibular units undergo considerable change in activity consequent upon the disappearance of the effect of the gravitational constant. The change assumes a periodic character in the first three days of the flight, with an increasing tendency to approach the norm; on the fourth day overcompensation sets in, followed in the next 48 hours by a slow return to physiological conditions. The entire phenomenon can be attributed to spontaneous sense organ activity and is therefore of particular importance in the case of those organs or systems that are controlled by the inner ear, such as the heart, the circulation, the digestion and movements (especially of the eyeballs). Even beyond the confines of the specific field of space these results represent the first direct investigation of the ability of a sense organ to modify its behavior in response to an environmental change and to slowly adapt itself to it, i.e. the first investigation to consider changes corresponding to a learning or training process on the level of the individual units composing an organ. These changes, as if in justification of Berry's hypotheses, can explain the emergence of space sickness symptomatology in the first few days of orbital flight; further, a progressive adaptation can be observed that finally becomes complete. We can therefore conclude -- at least insofar as the vestibular function is concerned -- that introduction of artificial gravity aboard spacecraft is not indispensable. Should this situation be confirmed for other systems of the organism (and this can be accomplished only by means of further experiments under orbital flight conditions), the final conclusion would be that man can adapt himself to the absence of weight and therefore to living in space or on planets with a low gravitational attraction. In that event physicist Ivanov could design his closed-cycle oxygen and water bioregeneration system for a zero G environment.

This however does not mean that man can move from the terrestrial gravitational field to weightlessness and vice versa with impunity: just what does happen when persons who have lived and worked for a long time in spacecraft flying to other worlds, in artificial satellites and in orbiting stations, finally return to earth? An experiment similar to OFO-A but in the opposite direction might reveal the behavior of the vestibular units when a change is effected from gravity 0 to gravity 1, and this is precisely the purpose of a forthcoming space flight being planned as a joint Italoamerican venture, perhaps using the Italian launching base at San Marco. Our hypothesis seems to have been confirmed by biological results from the Apollo 15 flight: together with about 15 other Italian scientists I had the good fortune to converse at length with the three Apollo 15 astronauts, D.R. Scott, A.M. Wardenand J.B. Irwin; and the last-named astronaut reported a symptomatology that is on the same footing with the results obtained by the OFO-A vestibular experiment at the same time that it seems to confirm the existence of considerable and prolonged aftereffects subsequent to return to earth. Irwin says that he experienced a sensation of disorientation for the first three days of the flight toward the moon (compare the three days of abnormal activity of the vestibular sensory cells of the bullfrogs in the OFO-A experiment): it seemed to him, when he was lying down, that he was inclined at an angle of 30 degrees relative to the horizon, corresponding to his reference points in the space capsule; and, after sleeping in a sort of hammock, it happened that he woke up with his body actually inclined at an angle of 30 degrees, as though his equilibrium control center had "believed" his new reference point and had therefore ordered his organism to assume the corresponding change in position. In the following days of the flight the situation returned to normal (compare the similar data of the OFO-A experiment). After returning to earth, vertigoes, disorientation and other typical symptoms of motion sickness lasted a good seven days and then disappeared completely.

Just what this would seem to indicate is the existence of delayed vestibular changes and the necessity of a certain period of readjustment to terrestrial conditions; alterations and readjustment that the second experiment (OFO-B) might demonstrate, just as OFO-A demonstrated those due to the emergence of conditions of weightlessness. This means that utilization of artificial gravity might be required only for those missions on which the individual has to be alert and efficient in changing from the one environmental condition to the other, from gravity 0 to gravity 1; or else a period of readjustment immediately after return to earth might be introduced as a general rule. The two measures might be combined by equipping spacecraft with specially designed units which, halfway between artificial satellite and earth, would gradually rehabituate the human being to gravity 1.

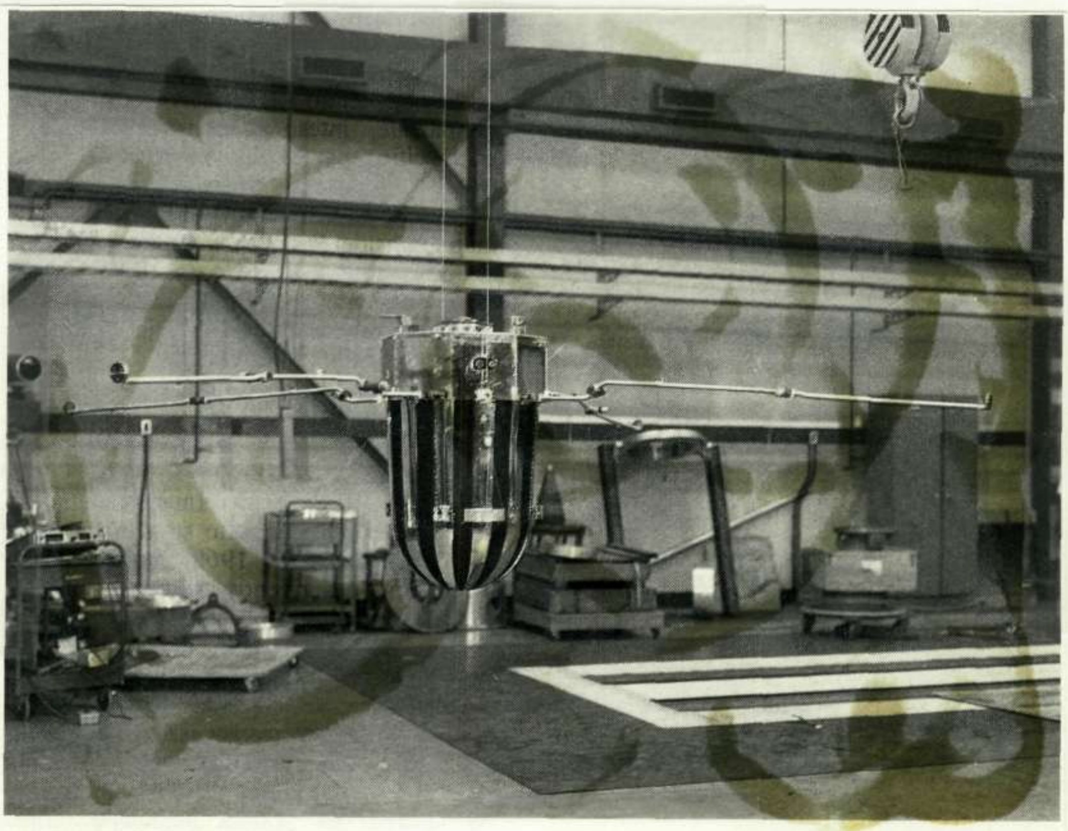
While these conclusions and hypotheses are strictly pertinent only to the subject of space, the OFO-A experiment did yield other, more general results. It was a completely automatic experiment that lasted, as we have said, more than six consecutive days and essentially consisted in recording the characteristic nervous activity of individual sense organs in the vestibular system of animals kept under physiological conditions. As a corollary, many theoretical problems had to be solved, which opened new avenues of research on biological phenomena in the broad sense. With the same techniques invented for the requirements of the space experiment we are now in a position to study the activity of individual elements of any system in normal animals, i.e. not having been subjected to surgical trauma or, worse still, massive destruction just before the study; and to construct constant environments between predetermined and significant limits, and for a long enough time to include different periods of 24 hours which, as is known, constitute the base life cycle of all terrestrial creatures. It is moreover possible to record biological phenomena with no danger of disturbances or adulterations due to mechanical promptings that are either spontaneous or determined by the surrounding environment; i.e. the animal can freely carry on its own activity while a particular element of its organism is being continuously analyzed. Hitherto this has not been possible, and individual units were studied in immobilized animals, or animals that had recently undergone more or less damaging operations, under almost preagonal conditions and for no longer than an hour or two.

The study of selected individual elements on the cellular level as a function of time and in response to a normal or imposed environmental condition is a new and important enough concept in biology to justify, in my opinion, the use of the means and the human effort that are characteristic of space projects.

Prosecution of this line of research may not be possible at the present time owing to a different utilization of available means or, perhaps above all, owing to that curious phenomenon of mental fatigue that crops up periodically in the great currents of human progress. In the above mentioned conversation with the three Apollo 15 astronauts, Scott, the head of the mission and undoubtedly the most "mature" of the three, was asked whether he did not feel bad about the imminent cessation of the American lunar exploration program just when it was beginning to yield significant scientific results. As is indeed known, after Apollo 16 and 17 (the latter flight being particularly rich in important experiments, a veritable gold mine of scientific information) there will be no more flights to the moon on the part of the United States. Scott replied that he was sure the Americans would get around to the moon again, even if it took many years, perhaps with more refined and more fundamental objectives, until the "colonization" of our satellite; and he pointed out that the same thing had happened in the case of antarctic exploration, which was conducted with great vigor until the first decade of this century, when it was abandoned until the present time, only to be resumed with greater intensity and more important objectives than ever before. According to Scott, the same fate is undoubtedly in store for the space program, now in dire straits throughout the world.

On this optimistic note I will conclude, and the reader of today or of the day after tomorrow, as he ponders the first faltering steps beyond the earth that we took in the last fifteen years, may answer: It was worth it.

Torquato Gualtierotti was born, studied and took his degree in Milan. Since 1962 he has occupied the second chair in human physiology in the University of Milan Medical and Surgical School. He spent almost four years at the Ames Research Center of NASA at Moffett Field, California, where he busied himself with the space program. His special field is neurophysiology. With regard to the space program he is interested in the physiology of the cerebellar and vestibular systems in connection with the problem of equilibrium and weightlessness.



OFO-A artificial satellite, with unfolded antennas and stabilizers, undergoing tests at NASA base on Wallops Island, Virginia

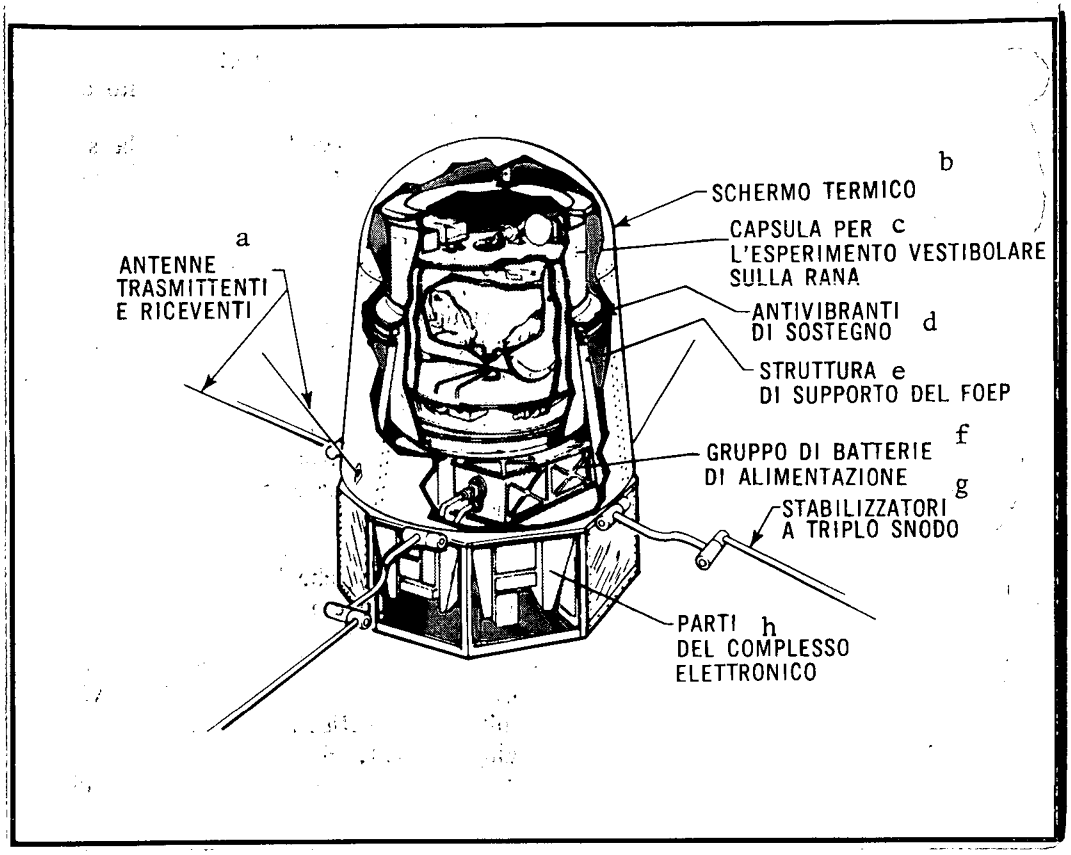
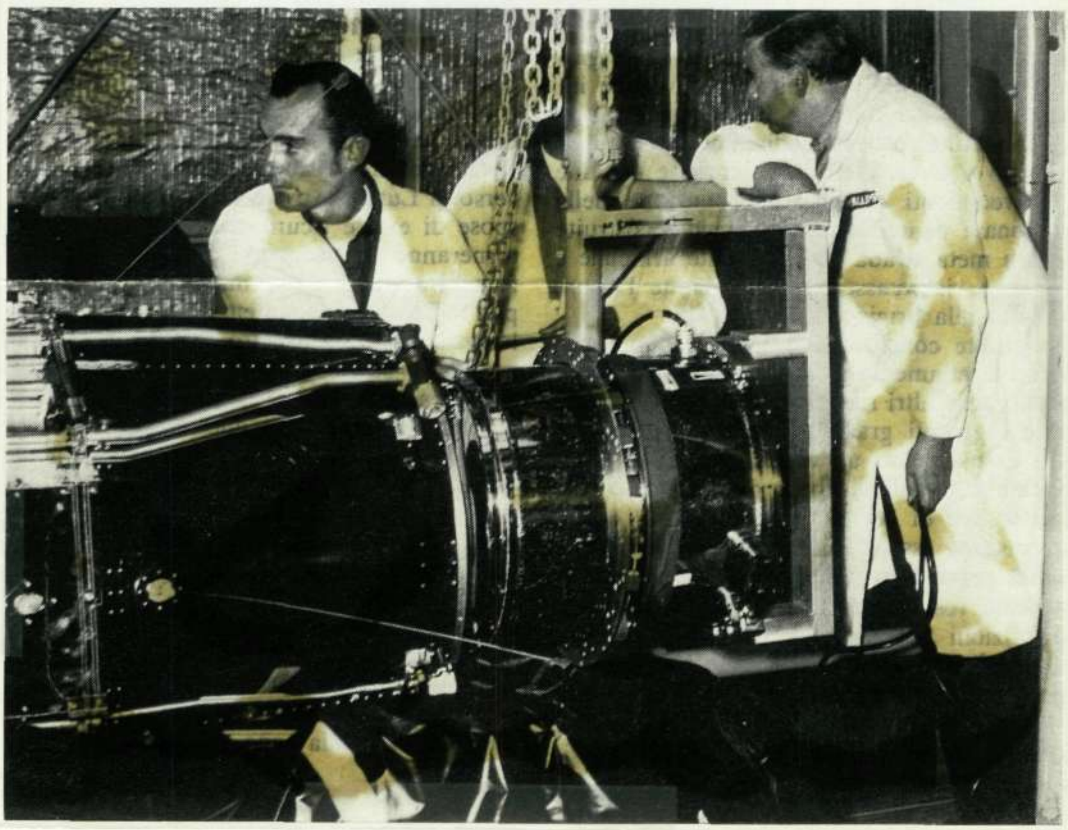


Diagram of OFO-A satellite containing space capsule

KEY

a. Transmitting and receiving antennas
b. Heat shield
c. Capsule for vestibular experiment on frog
d. Antivibration support
e. FOEP supporting framework
f. Battery bank
g. Triple-jointed stabilizers
h. Electronic components

The author and a technician introduce into the space capsule one of the bullfrogs already saddled with instruments



The space capsule inside a hermetically sealed container being inserted in the OFO-A satellite fixed to the "nose" of the Scout rocket, in a horizontal position